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(54) **METHOD AND SYSTEM FOR PROVIDING MAGNETIC RESONANCE IMAGES**

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(57) **ABSTRACT**

An embodiment of the invention relates to a method for providing magnetic resonance images of a foetus or a mother carrying a foetus, the method comprising the steps of:

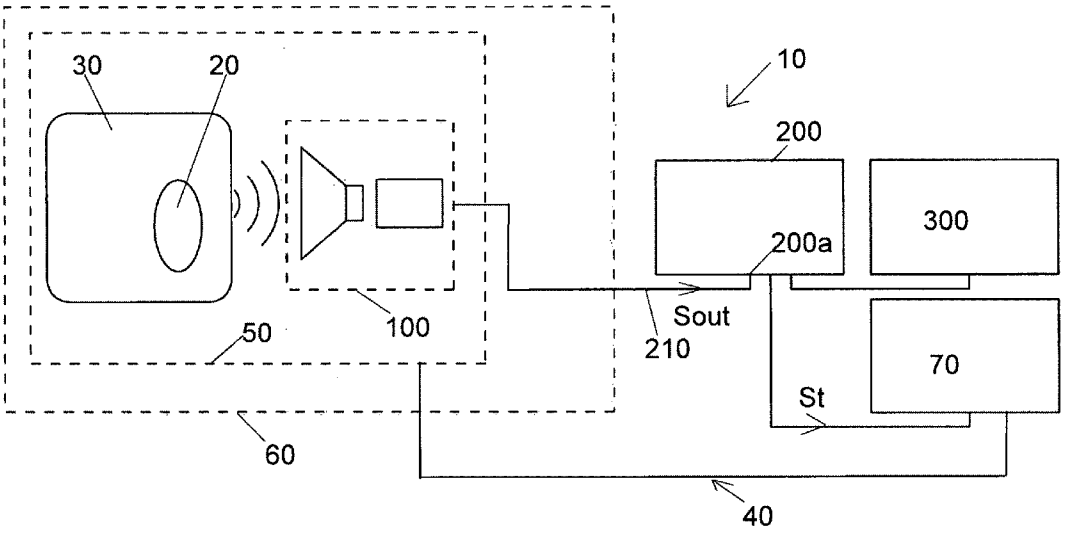
applying an ultrasonic transceiver to the mother's body and inducing an ultrasonic signal into the mother's and foetus's body;

receiving a returned ultrasonic signal and providing an output signal;

processing the output signal in order to generate a trigger signal indicating the heart activity of the foetus;

triggering a magnetic resonance imaging device taking the trigger signal into account; and

generating magnetic resonance images of the foetus or the mother by using the triggered magnetic resonance imaging device.



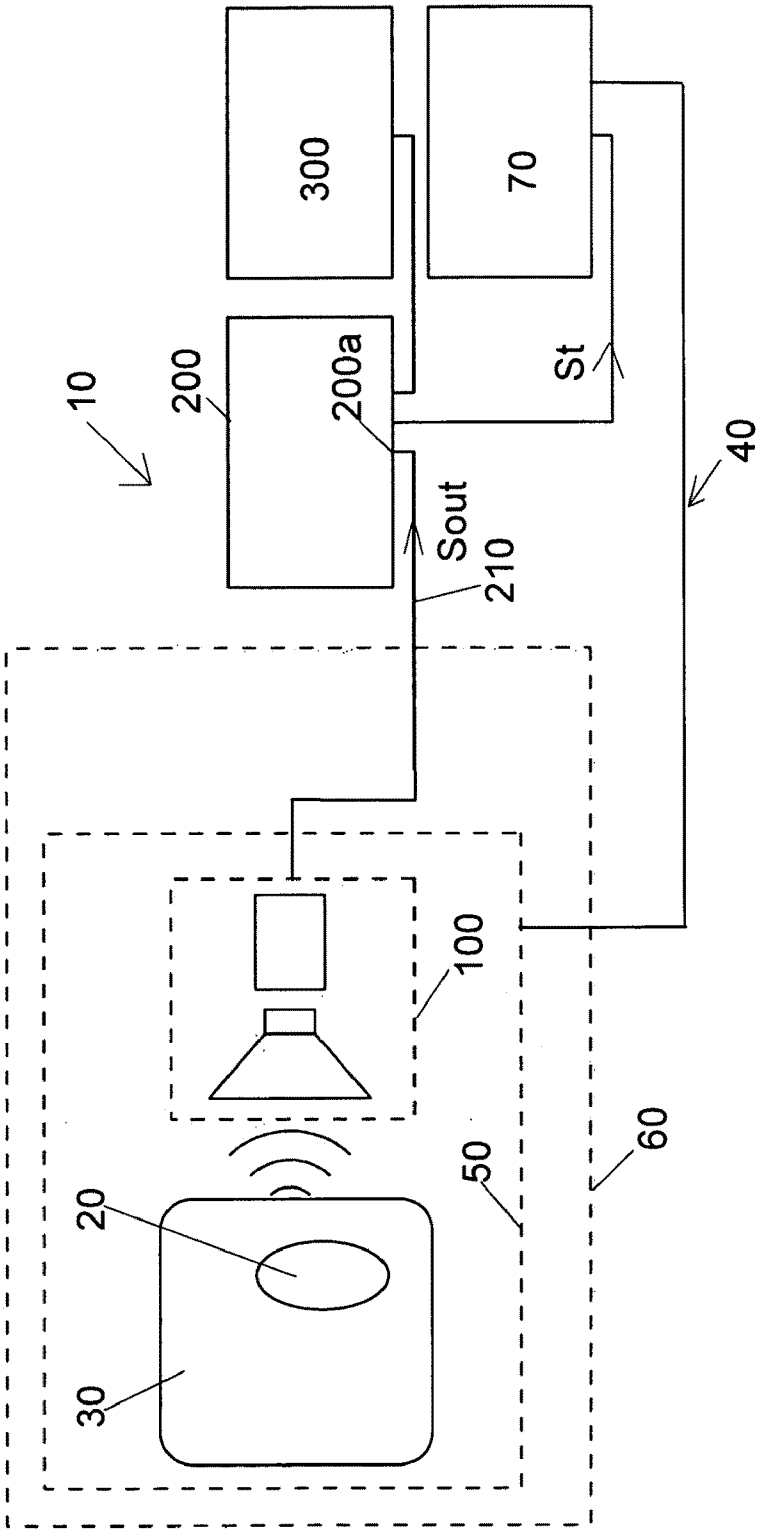


Fig. 1

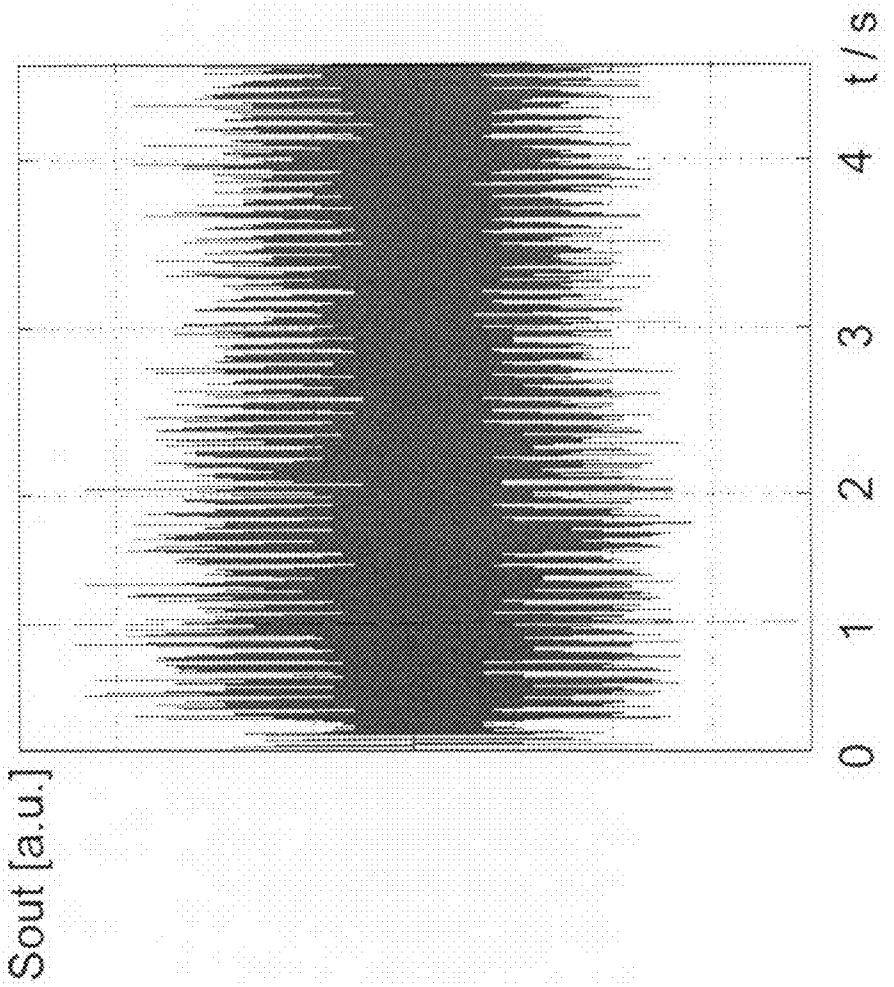


Fig. 2

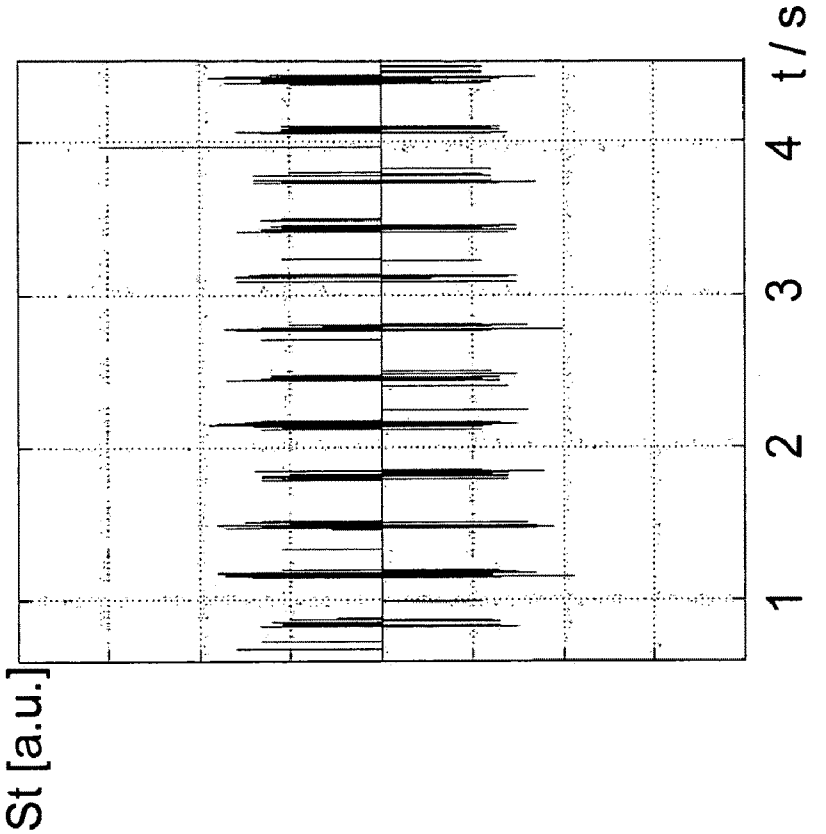


Fig. 3

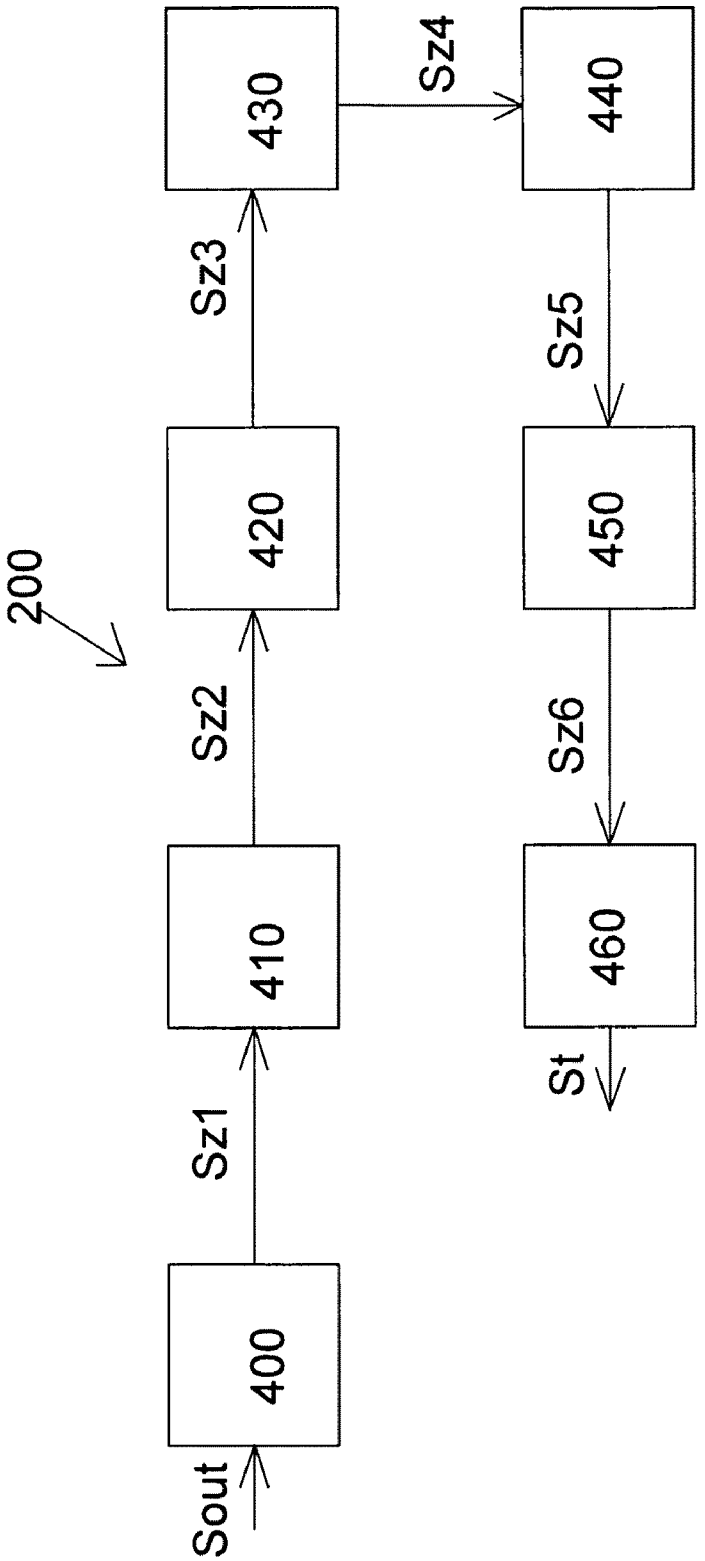


Fig. 4

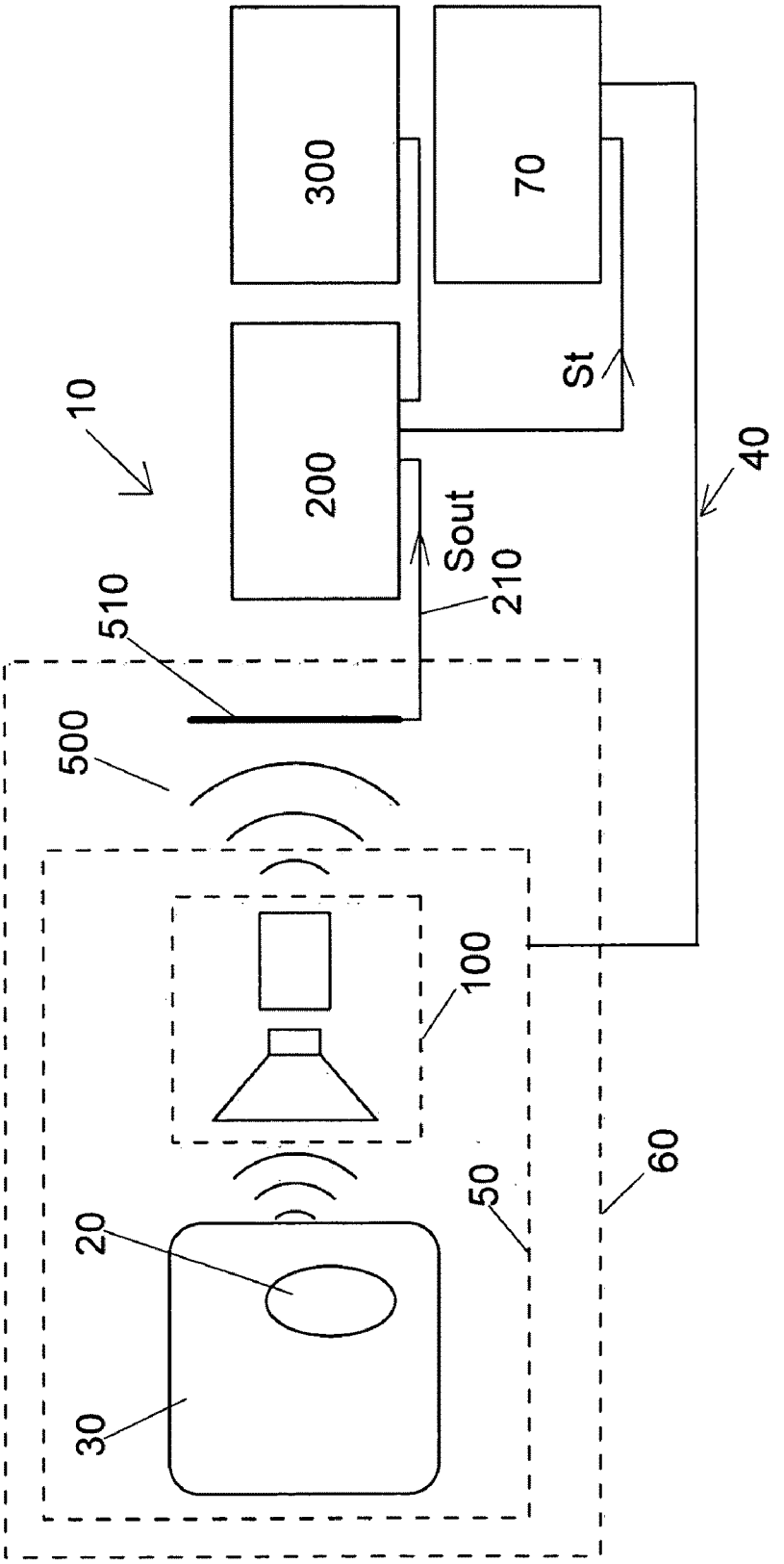


Fig. 5

METHOD AND SYSTEM FOR PROVIDING MAGNETIC RESONANCE IMAGES

BACKGROUND OF THE INVENTION

[0001] The invention relates to a method and system for providing magnetic resonance images of a foetus or a mother carrying a foetus.

[0002] Various diagnostic approaches exist for the exploration of foetal heart disease. Today, imaging modalities have an integral part in prenatal diagnostics; i.e. conventional echocardiography and magnetic resonance imaging (MRI). Although MRI shows superior soft tissue contrast, foetal cardiac imaging for prenatal heart function assessment is performed with ultrasonography in clinical routine. This is explained by insufficient visibility of moving structures with MRI.

[0003] Problems, which occur when imaging moving organs with MRI, may be avoided by triggering the MRI. However, in vivo foetal cardiac MRI still lacks a feasible triggering concept, which is safe for both foetus and mother and allows reliable and fast detection of foetal heart sounds.

[0004] Motion artefacts, which occur when imaging moving organs with

[0005] MRI, may be avoided with triggered or fast image acquisition. However, in foetal cardiac imaging, electrocardiographic (ECG) MRI triggering is associated with unjustifiable risks. Foetal ECG requires an cabled electrode to be invasively placed on the foetus's head, through which currents may be induced from the MRI and shock the foetus and the mother.

[0006] Foetal cardiac imaging may also be accomplished by reducing the duration of image acquisition with fast gradient systems in combination with sequence optimization and parallel imaging. However, the design of fast gradient systems is limited by the risk of peripheral nervous stimulation, and image quality will typically reduce with faster sequences.

OBJECTIVE OF THE PRESENT INVENTION

[0007] An objective of the present invention is to provide a method and system which delivers images of a foetus or a mother carrying a foetus in a safe manner.

[0008] A further objective of the present invention is to provide a method and system which avoids artefacts when capturing images of a foetus or a mother carrying a foetus.

[0009] A further objective of the present invention is to provide a method and system which can be carried out without cabled electrodes invasively placed on the foetus's head.

BRIEF SUMMARY OF THE INVENTION

[0010] An embodiment of the invention relates to a method for providing magnetic resonance images of a foetus or a mother carrying a foetus, the method comprising the steps of:

[0011] applying an ultrasonic transceiver to the mother's body and inducing an ultrasonic signal into the mother's and foetus's body;

[0012] receiving a returned ultrasonic signal and providing an output signal;

[0013] processing the output signal in order to generate a trigger signal indicating the heart activity of the foetus;

[0014] triggering a magnetic resonance imaging device taking the trigger signal into account; and

[0015] generating magnetic resonance images of the foetus or the mother by using the triggered magnetic resonance imaging device.

[0016] Preferably, the pictures are captured when the foetus's heart does not beat.

[0017] Another embodiment of the invention relates to a system for providing magnetic resonance images of a foetus or a mother carrying a foetus, the system comprising

[0018] a magnetic resonance imaging device;

[0019] an ultrasonic transceiver having

[0020] a transmitter adapted to provide an ultrasonic signal and adapted to induce the ultrasonic signal into the mother's body; and

[0021] a receiver adapted to receive a returned ultrasonic signal and to provide an output signal;

[0022] a trigger device connected to the ultrasonic transceiver, said trigger device being configured to process the output signal and to provide a trigger signal for triggering the magnetic resonance imaging device, said trigger signal indicating the heart activity of the foetus;

[0023] wherein said magnetic resonance imaging device is adapted to capture magnetic resonance images taking the trigger signal provided by the trigger device into account.

[0024] The ultrasonic sensor may comprise a Doppler ultrasonic sensor unit.

[0025] Preferably, the trigger device comprises a filter adapted to reduce the noise comprised in the output signal. For instance, the filter may be a Wiener-filter which is adapted to reduce the noise by comparison of the output signal with an estimation of the desired noiseless output signal.

[0026] Alternatively or additionally, the trigger device may comprise a comb filter configured to reduce disturbance frequencies generated by the magnetic resonance imaging device in the output signal.

[0027] Alternatively or additionally, the trigger device may comprise a fast Fourier transform unit configured to transform the output signal from the time-domain into the frequency-domain, and an inverse fast Fourier transform unit configured to transform the output signal from the frequency-domain back into the time-domain. In this specific embodiment, a comb filter is preferably arranged between the fast Fourier transform unit and the inverse fast Fourier transform unit.

[0028] Alternatively or additionally, the trigger device may comprise a band pass filter configured to reduce the bandwidth of the output signal in the frequency-domain. The bandwidth of the frequencies passing the band pass filter preferably corresponds to the typical spectrum of the foetus's heart sound. The band pass filter is preferably arranged between the fast Fourier transform unit and the inverse fast Fourier transform unit. The bandwidth of the band pass filter preferably ranges between 20 Hz and 180 Hz.

[0029] Alternatively or additionally, the trigger device may comprise a mean-value-filter which processes the signal outputted by the inverse fast Fourier transform unit.

[0030] Alternatively or additionally, the trigger device may comprise an auto- or cross-correlation function unit.

[0031] According to a preferred embodiment, the trigger device comprises

[0032] a Wiener-filter configured to reduce the noise by comparison of the output signal with an estimation of the desired noiseless output signal in the time-domain;

[0033] a fast Fourier transform unit configured to transform the output signal from the time-domain into the frequency-domain;

[0034] an inverse fast Fourier transform unit configured to transform the output signal from the frequency-domain back into the time-domain;

[0035] a comb filter configured to reduce disturbance frequencies generated by the magnetic resonance imaging device in the output signal, and to filter the output signal in the frequency-domain, said comb filter being arranged between said fast Fourier transform unit and said inverse fast Fourier transform unit;

[0036] a band pass filter configured to reduce the bandwidth of the output signal in the frequency-domain, said band pass filter being arranged between said fast Fourier transform unit and said inverse fast Fourier transform unit, wherein the bandwidth passing the band pass filter corresponds to the typical spectrum of the foetus's heart sound;

[0037] a mean-value-filter; and

[0038] an auto- or cross-correlation function unit.

[0039] The trigger device or the magnetic resonance imaging device may comprise a time-shifter unit in order to start the picture taking process whenever the foetus's heart does not beat.

[0040] The transceiver and the trigger device may be connected by a cable or wirelessly by a radio signal.

BRIEF DESCRIPTION OF THE DRAWINGS

[0041] In order that the manner in which the above-recited and other advantages of the invention are obtained will be readily understood, a more particular description of the invention briefly described above will be rendered by reference to specific embodiments thereof which are illustrated in the appended drawings. Understanding that these drawings depict only typical embodiments of the invention and are therefore not to be considered to be limiting of its scope, the invention will be described and explained with additional specificity and detail by the use of the accompanying drawings in which

[0042] FIG. **1** shows a first exemplary embodiment of an inventive system;

[0043] FIG. **2** shows an unfiltered output signal of a transceiver in an exemplary fashion;

[0044] FIG. **3** shows a filtered output signal of a transceiver in an exemplary fashion;

[0045] FIG. **4** shows an exemplary embodiment of a trigger device for the system of FIG. **1**; and

[0046] FIG. **5** shows a second exemplary embodiment of an inventive system.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0047] The preferred embodiment of the present invention will be best understood by reference to the drawings, wherein identical or comparable parts are designated by the same reference signs throughout.

[0048] It will be readily understood that the present invention, as generally described and illustrated in the figures herein, could vary in a wide range. Thus, the following more detailed description of the exemplary embodiments of the present invention, as represented in FIGS. **1-5**, is not intended to limit the scope of the invention, as claimed, but is merely representative of presently preferred embodiments of the invention.

[0049] FIG. **1** shows an exemplary embodiment of a system **10** for providing magnetic resonance images of a foetus **20** or a mother **30** carrying the foetus.

[0050] The system **10** comprises a magnetic resonance imaging device **40** comprising a picture taking unit **50** arranged inside a shielded room **60**, and a controller unit **70** arranged outside the shielded room **60**.

[0051] The system **10** further comprises an ultrasonic transceiver **100** having a transmitter adapted to provide an ultrasonic signal and adapted to induce the ultrasonic signal into the mother's body **30**. The ultrasonic transceiver **100** further comprises a receiver adapted to receive a returned ultrasonic signal and to provide a preferably sampled output signal Sout. The output signal Sout is depicted in FIG. **2** in an exemplary fashion.

[0052] Furthermore, the system **10** comprises a trigger device **200** arranged outside the shielded room **60** and connected to the ultrasonic transceiver **100** via a cable **210**. The cable **210** may be a shielded and electrically conductive cable which electrically transmits the output signal Sout. Alternatively, the cable **210** may be an optical cable such as an optical fiber which transmits the output signal Sout in an optical manner.

[0053] The trigger device **200** processes the output signal Sout and provides a trigger signal St for triggering the controller unit **70** and thus the entire magnetic resonance imaging device **40**. The trigger signal St is depicted in FIG. **3** in an exemplary fashion. It can be seen that the trigger signal St indicates the heart activity and the heart beat of the foetus.

[0054] The controller unit **70** controls the picture taking unit **50** according to the trigger signal Sout provided by trigger device **200** and thus avoids artefacts in the pictures captured. Preferably, the pictures are taken when the foetus's heart does not beat.

[0055] The system **10** may further comprise a foetal monitor **300** showing the signal provided by the ultrasonic transceiver **100**. Preferably the foetal monitor **300** indicates the foetal heartbeats as well as the mother's uterine contractions.

[0056] FIG. **4** shows an exemplary embodiment of the trigger device **200**. The trigger device **200** comprises a plurality of digital units which process the sampled output signal Sout.

[0057] A digital Wiener-filter **400** may be connected to an input **200***a* of trigger device **200** (see FIG. **1**). The Wiener-filter **400** applies the Wiener-Kolmogorov filtering theory and reduces the noise by comparison of the sampled output signal Sout with an estimation of the desired noiseless output signal in the time-domain.

[0058] The filtered signal Sz**1** provided by Wiener-filter **400** is inputted into a digital fast Fourier transform unit **410** which transforms the filtered signal Sz**1** from the time-domain into the frequency-domain.

[0059] The transformed signal Sz**2** reaches a digital band pass filter **420**. The band pass filter **420** transmits frequencies corresponding to the typical spectrum of the foetus's heart sound and blocks the other frequencies. Preferably, the spectrum for which the band pass filter **420** is transparent, ranges from 10 Hz to 200 Hz, for instance from 20 Hz to 180 Hz. The output signal of the band pass filter **420** is marked by reference sign Sz**3** in FIG. **4**.

[0060] The signal Sz**3** of the band pass filter **420** then enters a digital comb filter **430**. The Comb filter **430** reduces distur-

bance frequencies generated by the picture taking unit **50** of the magnetic resonance imaging device **40**. To this end, the comb filter **430** filters the signal Sz**3** in the frequency-domain. The frequencies fcomb filtered or blocked by the comb filter **430** are preferably given by the following equation:

$$fcomb=Q/TR$$

wherein TR is the repetition frequency of the picture taking unit **50**, i.e. the repetition frequency according to which the pictures are captured. Q is a set of natural numbers {1, 2, 3, . . . }.

[0061] The filtered signal which exits the comb filter **430** is marked by reference sign Sz**4** in FIG. **4**.

[0062] The trigger device **200** further comprises a digital inverse fast Fourier transform unit **440** which transforms the output signal Sz**4** of the comb filter **430** from the frequency-domain back into the time-domain.

[0063] The retransformed signal Sz**5** reaches a digital mean-value-filter **450** which reduces remaining noise carried by signal Sz**4**.

[0064] Preferably, the trigger device **200** further comprises an auto- or cross-correlation function unit **460** which filters the heart beat signal from residual signals. An autocorrelation function and/or an cross-correlation function can be calculated in time domain or in frequency domain.

[0065] For instance, the autocorrelation function can be calculated as follows:

$$S(f)=x^*(f)\cdot x(f)$$

wherein x(f) describes signal Sz**6** in the frequency domain and x*(f)the conjugate complex function thereof. The autocorrelation function may then be written as:

$$R_1(\tau)=\int_{-\infty}^{\infty} S(f)\cdot e^{i2\pi f\tau}\,df$$

[0066] The duration T_1 of the foetus's heart beat (heart cycle) results from a determination of the maximum of the autocorrelation function $R_1(\tau)$:

$$T_1=\max(R_1(\tau)) \text{ for } \tau\leqq 0.25 \text{ s}$$

[0067] Based on the value of T_1 the auto- or cross-correlation function unit **460** generates the signal St that may be used to trigger the controller unit **70** and thus the picture taking process.

[0068] In the manner described above in an exemplary fashion, pictures of the foetus and/or the mother can be taken at the appropriate moments in view of the foetal heart beat. For instance, the pictures can be captured in time frames when the foetus's heart does not interact, i.e. in time frames when the foetus's heart does not beat and thus does not influence the picture's quality. For instance, the pictures may be captured time-shifted to the trigger signal St in order to guarantee that the pictures are taken when the foetus's heart does not beat.

[0069] FIG. **5** shows a further exemplary embodiment of a system **10** for providing magnetic resonance images of a foetus **20** or a mother **30** carrying the foetus. The system **10** of FIG. **5** differs from system **10** of FIG. **1** in that the output signal Sout of the receiver is transmitted wireless via a radio signal **500** from the inside of the picture taking unit **50** to an antenna **510** arranged outside the picture taking unit **50** and inside the shielded room **60**. The cable **210** may be used to transmit the output signal Sout from the antenna **510** to the trigger device **200** in an electrical or optical manner.

[0070] The frequency of radio signal **500** is preferably outside the frequency range of the magnetic resonance imaging device **40** in order to avoid interference. For instance, for the radio signal **500**, a frequency of about 900 Mhz may be used. Alternatively, a frequency range between 2.4 GHz und 2.5 GHz, e. g. according to or in view of Bluetooth standard IEEE 802.15.1 or WLAN standard IEEE 802.11 (WLAN: Wireless Local Area Network) may be used. It is also possible to use higher frequencies, for instance between 5 GHz und 6 GHz, e. g. according to or in view of the WLAN standard.

[0071] In the system **10** shown in FIGS. **1** and **5**, the trigger device **200** or the magnetic resonance imaging device **40** may comprise a time-shifter unit for triggering the picture taking process time-shifted relative to the foetus's heart beat.

REFERENCE SIGNS

[0072] **10** system
[0073] **20** foetus
[0074] **30** mother
[0075] **40** magnetic resonance imaging device
[0076] **50** picture taking unit
[0077] **60** shielded room
[0078] **70** controller unit
[0079] **100** ultrasonic transceiver
[0080] **200** trigger device
[0081] **210** cable
[0082] **300** foetal monitor
[0083] **400** Wiener-filter
[0084] **410** fast Fourier transform unit
[0085] **420** band pass filter
[0086] **430** comb filter
[0087] **440** inverse fast Fourier transform unit
[0088] **450** mean-value-filter
[0089] **460** auto- or cross-correlation function unit
[0090] **500** radio signal
[0091] **510** antenna
[0092] Sout signal
[0093] Sz**1**-Sz**7** signal
[0094] St signal

1. Method for providing magnetic resonance images of a foetus or a mother carrying a foetus, the method comprising the steps of:
- applying an ultrasonic transceiver to the mother's body and inducing an ultrasonic signal into the mother's and foetus's body;
- receiving a returned ultrasonic signal and providing an output signal;
- processing the output signal in order to generate a trigger signal indicating the heart activity of the foetus;
- triggering a magnetic resonance imaging device taking the trigger signal into account; and
- generating magnetic resonance images of the foetus or the mother by using the triggered magnetic resonance imaging device.

2. Method of claim **1** wherein the pictures are captured time-shifted to the foetus's heart beat.

3. System for providing magnetic resonance images of a foetus or a mother carrying a foetus, the system comprising
- a magnetic resonance imaging device;
- an ultrasonic transceiver having

a transmitter adapted to provide an ultrasonic signal and adapted to induce the ultrasonic signal into the mother's body; and

a receiver adapted to receive a returned ultrasonic signal and to provide an output signal;

a trigger device connected to the ultrasonic transceiver, said trigger device being configured to process the output signal and to provide a trigger signal for triggering the magnetic resonance imaging device, said trigger signal indicating the heart activity of the foetus;

wherein said magnetic resonance imaging device is adapted to capture magnetic resonance images taking the trigger signal into account.

4. System of claim **3** wherein said ultrasonic sensor is a Doppler ultrasonic sensor.

5. System of claim **3** wherein said trigger device comprises a filter adapted to reduce the noise comprised in the output signal.

6. System of claim **5** wherein said filter is a Wiener-filter which is adapted to reduce the noise by comparison of the output signal with an estimation of the desired noiseless output signal.

7. System of claim **3** wherein said trigger device comprises a comb filter configured to reduce disturbance frequencies generated by the magnetic resonance imaging device in the output signal.

8. System of claim **3** wherein said trigger device comprises

a fast Fourier transform unit configured to transform the output signal from the time-domain into the frequency-domain; and

an inverse fast Fourier transform unit configured to transform the output signal from the frequency-domain back into the time-domain.

9. System of claim **6**

wherein said trigger device comprises a comb filter configured to comb-filter the output signal in the frequency-domain; and

wherein said comb filter is arranged between said fast Fourier transform unit and an inverse fast Fourier transform unit.

10. System of claim **8** wherein said trigger device comprises a Wiener-filter adapted to reduce the noise by comparison of the output signal with an estimation of the desired noiseless output signal, said Wiener-filter being arranged between the trigger device's input interface and said fast Fourier transform unit.

11. System of claim **8**

wherein said trigger device comprises a band pass filter configured to reduce the bandwidth of the output signal in the frequency-domain;

wherein the bandwidth passing the band pass filter corresponds to the typical spectrum of the foetus's heart sound; and

wherein said band pass filter is arranged between said fast Fourier transform unit and said inverse fast Fourier transform unit.

12. System of claim **11** wherein the bandwidth passing the band pass filter includes the frequency range between 20 Hz and 180 Hz.

13. System of claim **8** wherein the trigger device comprises a mean-value-filter which processes the signal outputted by the inverse fast Fourier transform unit.

14. System of claim **3** wherein the trigger device comprises a auto- or cross-correlation function unit.

15. System of claim **3** wherein said trigger device comprises

a Wiener-filter configured to reduce the noise by comparison of the output signal with an estimation of the desired noiseless output signal in the time-domain;

a fast Fourier transform unit configured to transform the output signal from the time-domain into the frequency-domain;

an inverse fast Fourier transform unit configured to transform the output signal from the frequency-domain back into the time-domain;

a comb filter configured to reduce disturbance frequencies generated by the magnetic resonance imaging device in the output signal, and to filter the output signal in the frequency-domain, said comb filter being arranged between said fast Fourier transform unit and said inverse fast Fourier transform unit;

a band pass filter configured to reduce the bandwidth of the output signal in the frequency-domain, said band pass filter being arranged between said fast Fourier transform unit and said inverse fast Fourier transform unit, wherein the bandwidth passing the band pass filter corresponds to the typical spectrum of the foetus's heart sound;

a mean-value-filter; and

an auto- or cross-correlation function unit.

16. System of claim **3** wherein said trigger device or the magnetic resonance imaging device comprises a time-shifter unit.

17. System of claim **3** wherein the transceiver is wirelessly connected to the trigger device.

* * * * *